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A PARAMETRIC STUDY ON EFFECT OF FLY ASH TOGETHER WITH FIBER FOR SUSTAINABLE CONCRETE

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ABSTRACT

The present challenge for civil engineers is to produce high volume and high performance fly ash concrete with increased durability and service life, at lowest possible cost. Also concrete produced should have minimal negative impact on the environment, which is green and sustainable concrete. This can be achieved by reducing the use of natural lime, fine and coarse aggregates whose resources are limited and are depleting very fast day by day. It could also be achieved by utilizing maximum possible industrial by-product like fly ash in concrete as it would reduce landfill area for fly ash disposal and CO_2 *emission during cement manufacturing process. Effect of fly ash as replacement of cement together with fibers in concrete on durability is very well reported in literatures. However effect of fly ash as partial replacement of cement and sand together with fibers is not clearly available in literatures. Literatures show that partial replacement of cement by fly ash reduces early age strength of concrete. Partial replacement of sand by fly ash together with fiber shall compensate strength loss due to partial replacement of cement by fly ash. Due to government restrictions on natural sand mining from river beds, contractors are demanding a reliable and all weather partial or full replacement material for sand. Present study shall be a right step forward in reducing consumption of natural sand and consuming higher volumes of fly ash available in Chhattisgarh region together with fibers for sustainable and durable concrete.*

Key words: Durability, Fiber, Fly Ash, Sand, Sustainable.

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1. INTRODUCTION

Concrete is the most widely used construction material all over the globe after water. The present challenge for civil engineers is to produce high volume, high performance, durable and sustainable concrete at lowest possible cost. This can be achieved by utilising maximum possible industrial by-product like fly ash together with fiber in concrete.

Fly ash, known as pulverized fuel ash, is the ash precipitated electrostatically or mechanically from the exhaust gases of coal-fired power station. India consumes large amounts of cement and also produces over 184 millions tones of fly ash per year [1]. According to notification of Ministry of Environment and Forest 100% utilization of produced fly ash must be achieved in the year 2013. However as per available reports only 56% of it is used. In case of Chhattisgarh state utilization is even lower at about 40%. Fly ash production is expected to reach 300 million tons Per annum by 2017 and 900 million tons per annum by 2031-2032 [2]. Management of huge quantity of fly ash shall require huge land area for dumping and it will be an environmental threat for coming generations if not handled properly.

Many previous studies concluded that fibers and fly ash are effective for improving the various properties of concrete. The benefits of using fly ash are that it reduces the cost of the concrete, carbon dioxide emission to environment, heat of hydration at early age and can improve the workability, long term strength and durability of concrete [3]. It has also been reported that damage due to shrinkage is significantly reduced in concrete or in cement paste when fibers and fly ash are added. New methods for higher utilization of fly ash in concrete should be urgently required for effectively utilising generated fly ash. Partial replacement of cement and sand with fly ash together with fiber may make it possible to consume higher volumes of fly ash produced making it a sustainable and durable concrete.

2. EFFECT OF PARTIAL REPLACEMENT OF CEMENT BY FLY ASH TOGETHER WITH FIBERS

Many previous literatures on study of the various properties of concrete containing different fibers and fly ash concluded that when fly ash is used together with fibers, the resulting concrete possesses desirable properties at reduced costs also. Following are the properties discuss shortly.

2.1. Effect on workability

It is well known that addition of fiber in concrete reduces the workability, because fibers hindered the flowability of fresh concrete and this caused the decrease in workability. However workability increased by adding fly ash in concrete. Researchers studied concrete produced with fly ash together with different types of fibers and they concluded that addition of fiber provide better performance of the concrete, while fly ash in the mixture may adjust the workability [4]. Research using fly ash content 0%, 15% and 30% by mass of cement and polypropylene fiber 0%, 0.05%, 0.10% and 0.20% in volume basic, results showed that addition of fiber in fresh concrete reduces the slump value, also the workability of concrete is reduced as the percentage of fibers is increased but by using fly ash some of the workability loss was compensated [5]. Researcher reported similar results with steel fibers [6]. Study on effect of steel and polypropylene fibers on the mechanical properties of concrete containing fly ash, results shows that addition of fibers provides better performance for the concrete, also adding

fiber caused 2-8% decrease in the workability of concrete, while addition of fly ash compensated for the lost workability [7].

2.2. Effect on strength

Study on the concrete containing fly ash between 0% to 30% and steel fibers dosage between 0% to 1.5% reported that addition of steel fiber either into Portland cement concrete or fly ash concrete improves the tensile strength properties, drying shrinkage and freeze–thaw resistance. The presence of fly ash, when compared with plain concrete, decreased the average compressive strength by 10% and 14% for 15% and 30% fly ash replacement ratio respectively. But after 365 days, due to pozzolanic reaction of fly ash and addition of steel fiber the loss in strength due to the replacement of cement with was compensated. Splitting tensile strength increased up to 71% for concrete mix having 1.5% volume fractions of fibers [6].

Inclusion of polypropylene fiber dosage up to 0.2% and fly ash as replacement of cement up to 30% in concrete reduced the compressive strength up to 30% [5]. The redistribution of void structure due to the inclusion of fiber, and the presence of weak interfacial bonds between the fiber and cement-fly ash grains, the compressive strength slightly decreased.

Alkali-resistant glass fibers at about 1% mass fraction (0.25% volume fraction) are quite effective in enhancing the material properties of the lightweight concrete mixtures [8]. The Investigation using replacement of cement with fly ash at level of 0%, 10%, 15% and 20% by weight with steel fiber and polypropylene fiber, the compressive strength and bending strength of concrete produced with fibers were increased compared to concrete produced without fibers. The 28 days compressive strength is to be similar for polypropylene fibers and 13% higher for steel fibers compared to control concrete, and up to 7% cost saving was observed with 15% replacement of cement with fly ash [7].

2.3. Effect on durability

Improving the properties of concrete using 30% fly ash, 1% polypropylene fiber by weight and 1% superplastizer by mass, result was 1% superplastizer delayed the initial and final setting times by 2-4 hours but addition of polypropylene fiber accelerating effect on the setting times of grout mixes, replacement of cement with 30% of fly ash produced economical grouts with reasonable physical properties, grouts containing appropriate amount of superplastizer enhanced flowability and viscosity, higher strengths, and reduced permeability [9]. Heterogeneities in the microstructure of the hydrated Portland cement paste, especially the existence of large pores and large crystalline products in transition zone, were greatly reduced by introduction of fine particles of fly ash [10]. Unit weight of concrete increased uniformly with the increase in fiber content and decreased with the increase of fly ash content [6]. Vitreous (glass) smooth and non-absorbing surface texture of fly ash is responsible for better workability and lower water requirement of pastes, mortars and concretes containing siliceous by-products as cement replacement [11].

2.4. Effect on shrinkage

Polypropylene fiber and fly ash in concrete separately or together reduced the drying shrinkage. Fly ash content in concrete mixture was 0%, 15% and 30% in mass basic, and fiber volume fraction was 0%, 0.05%, 0.10% and 0.20% in volume basis. On the basis of 210 days results, drying shrinkage reduced up to 17% when compare to Portland cement control mixture, with 0.20% fiber volume fraction. Similarly drying shrinkage reduced up to 30% using fiber volume fraction 0.20% with 15% fly ash contain [5].

Study on effects of different fibers on expansion of concrete with high content of fly ash. The ratio of cement/HFA was fixed to 0.50 with volume fraction of carbon fiber 1%, steel fiber 1%, nylon fiber 1% and glass fiber 0.5%, 1% and 1.5% respectively, and the result have shown that the glass and carbon fibers had greater restrain effect on the expansion and the values of their expansion were 54% and 36% of that of control specimen at the age of 60 days respectively. While the effect of steel fiber on restraining expansion was much less than those of glass and carbon fibers, and nylon fiber did not have any restraint effect on the expansion. The result is better in glass and carbon fiber because of carbon and alkali resistance glass fibers have high elastic modulus than steel and nylon fibers, expansion of composite decreases with increasing glass fiber volume fraction [12].

Study by using fly ash and steel fibers on shrinkage properties at 210 days. Fly ash content used was 0%, 15% and 30% in mass basis, and fiber volume fraction was 0%, 0.25%, 0.5%, 1.0% and 1.5% in volume, the result shows that maximum drying shrinkage occurred in Portland cement concrete mixture. While fly ash concrete without fiber shrank less than that of the reference Portland cement concrete. Concrete mixtures that contained 0.25%, 0.50%, 1.0% and 1.5% steel fiber resulted with 10%, 21%, 25% and 26% reductions in drying shrinkage, when compared to reference Portland cement mixture at the age of 210 days. Drying shrinkage in concrete mixes with 15% and 30% fly ash reduced up to 21% and 22% respectively when compared to reference fly ash concrete without steel fiber respectively. They also showed that addition of 30% fly ash and 1.5% dosage of steel fibers in concrete together reduced the shrinkage by 30% when compared to reference concrete [6].

To reduce the impact of early age shrinkage on concrete durability the addition of low volumetric fractions of short alkali resistance glass fiber is very advantageous in order to control crack growth. Alkali resistance glass fiber control the cracking produced due to very early age shrinkage on both self compacted concrete and standard concrete also reduces total cracked area and the maximum length of the cracks [13]. For long-term durability of the glass fiber reinforced polymer bars, it has been shown that alkali resistance glass fibers have a better resistance to alkaline environments than normal E-glass [14]

Addition of low volume fraction of AR-glass fiber (600gm/m^3) produced a minimum value of both cracked area and maximum cracked length, result showed that for some volume fraction and fiber length, the reduction of cracked area reaches up to 95% [15]. The early age shrinkage could be reduced by adhesion between the glass fibers filaments and cementations matrix. [16]

The above literatures show that the addition of fly ash and different fibers improve various properties of concrete. Inclusion of fly ash compensates for loss of workability due to fibers. Also inclusion of fibers increases 28 days strength of fly ash concrete.

3. EFFECT OF PARTIAL REPLACEMENT OF SAND WITH FLY ASH

3.1. Effect on workability and water requirement of concrete

Researcher made an extensive laboratory based investigation in to unprocessed low lime fly ash in foamed concrete, as a replacement for sand. For a given plastic density, the spread obtained on fly ash concretes were up to 2.5 times greater than those noted on sand mixes [17].

Need to use about 650 kg/m^3 of fine material to make self compacting concrete. This also requires fine aggregates more than 50% of total aggregate so that coarse aggregate can float in the fine material. This requirement of fine materials can be easily fulfilled by use of fly ash [18]. About 25% increases in workability of the fly ash based concrete over control concrete [19].

3.2. Effect on strength on concrete

An experimental investigation to evaluate mechanical properties of concrete mixes in which fine aggregate was partially replaced with five percentages (10%, 20%, 30%, 40% and 50 %) of class F fly ash by weight. The test result showed that the compressive strength, split tensile strength and flexural strength of fly ash concrete mixes with 10% to 50% fine aggregate replacement with fly ash were higher than control mix at all ages. Also the compressive strength shown in Fig. 1, split tensile strength shown in Fig. 2 and flexural strength shown in Fig. 3 of concrete mixes was increasing with increase in fly ash percentages. This increase in strength due to replacement of fine aggregate with fly ash was attributed to pozzolanic action of fly ash. The tests on modulus of elasticity also showed improvement in the results as compared to control concrete shown in Fig. 4 [20].

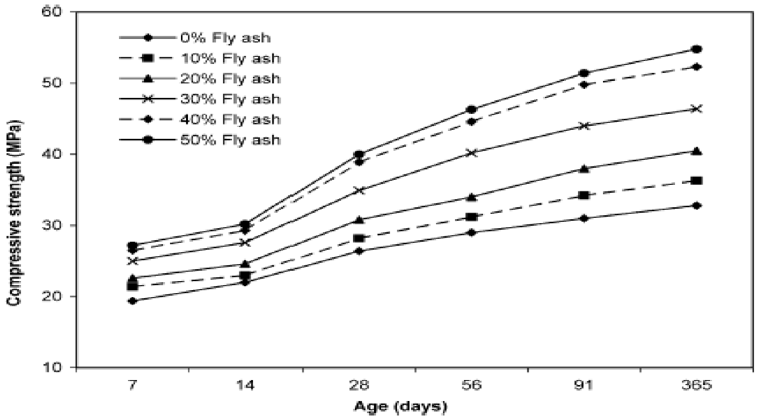

Figure 1 Compressive strength versus Age

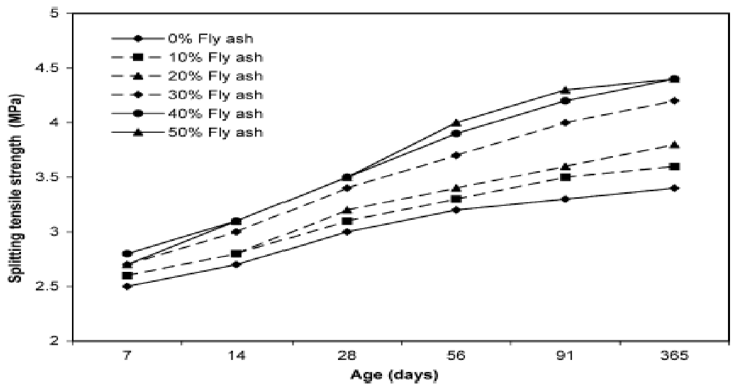

Figure 2 Splitting tensile strength versus Age

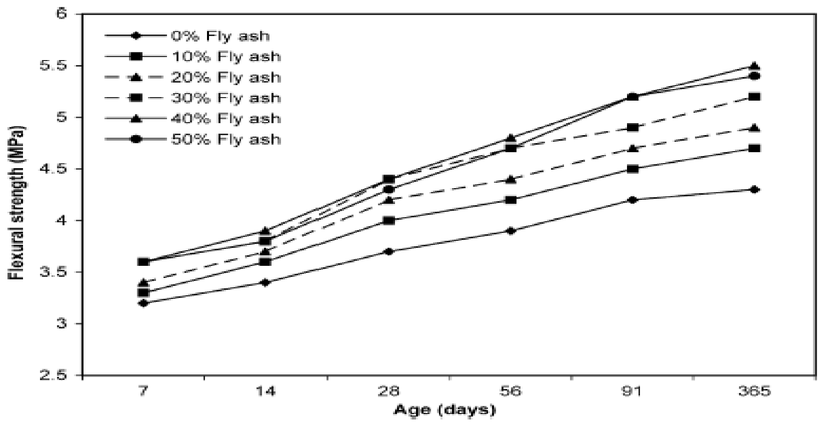

Figure 3 Flexural strength versus Age

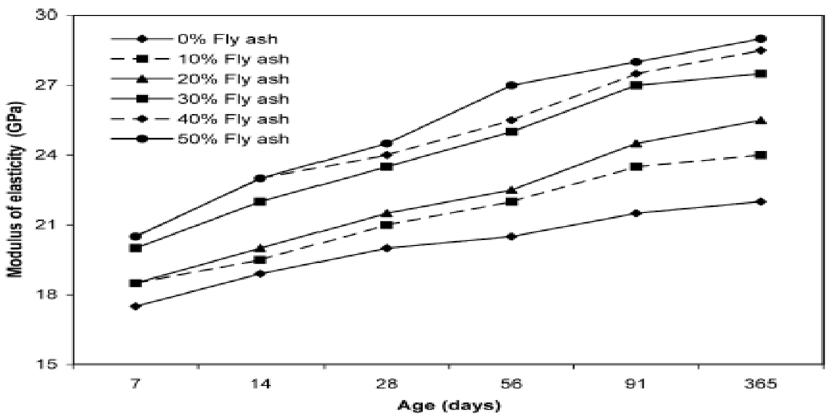

Figure 4 Modulus of elasticity verses Age

Research on the use of fly ash as replacement of sand in polymer concrete. The weight mix design having 10% resin, 45% pea gravels and 45 % sand was compared with weight mix design in which 15% sand was replaced by fly ash. This replacement of 15% sand with fly ash by weight increased compressive strength by about 30%. Also there was improvement in the stress strain curve as shown in Fig. 5; the reason for this was reported as addition of fly ash achieves better workability than sand. The fine and spherical particles of fly ash improves lubricating properties of polymer concrete, thus improving its plasticity and cohesiveness. They also conduct flexure test on polymer concrete beams with 15% fly ash replacement and result shows that flexural strength of steel reinforced polymer concrete beams was increased by 15% [21].

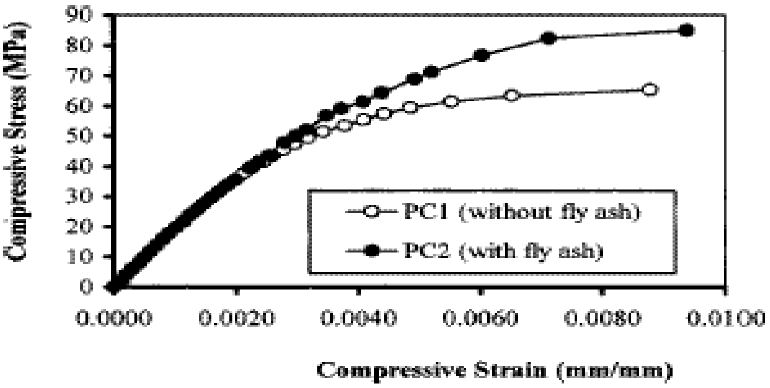

Figure 5 Polymer concrete Stress Strain Curve

Authors described early stages of a project to study the use of large volumes of high lime fly ash in concrete. Authors used fly ash for partial replacement of cement and fine aggregates. Replacement percent from 0% to 50% was tested in their study. They reported that concrete with 25% to 35% fly ash provided the most optimal results for its compressive strength. They concluded that this was due to the pozzolanic action of high lime fly ash [22].

Researchers used a typical low calcium fly ash as additive in mortar replacing, part of volume either of Portland cement or aggregate, in both cases 10%, 20% and 30% addition to the cement weight was done. A very important finding was that when the compressive strength of mix in which aggregate was replaced by fly ash were similar to that of control mix at 3 and 14 days, but were higher from 28 days and later, which is shown in the Fig. 6. The strength increase is due to higher content of calcium silicate hydrate (C-S-H, the main carrier of strength in hardened cement) due to reaction of CH produced from cement hydration with active silica of fly ash. There is reasonable distribution of the strength increases according to fly ash content but after 91 days there is no difference between 20% and 30% replacement. When fly ash replaces cement as shown in Fig. 7, the strength is reduced, at first due to lower activity of the fly ash, but as time precedes this gap is gradually eliminated [23].

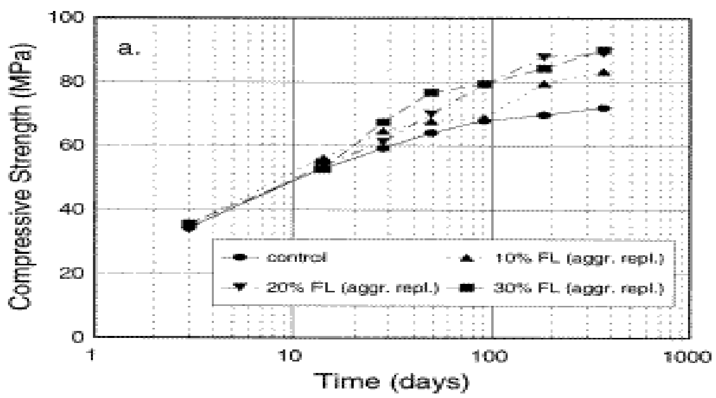

Figure 6 Compressive strength development of mortars when fly ash replaces aggregate

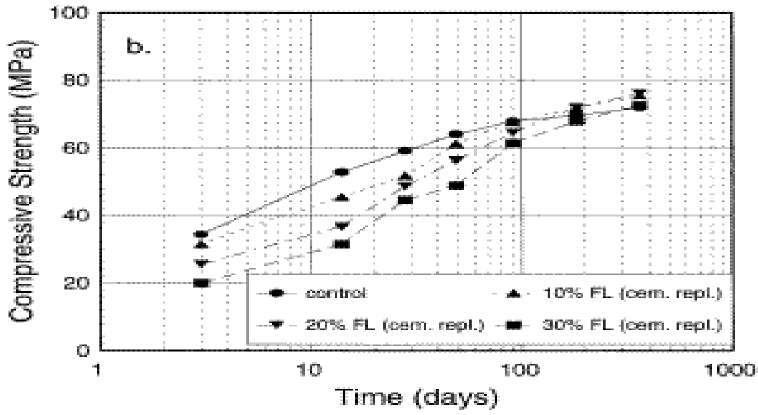

Figure 7 Compressive strength development of mortars when fly ash replaces cement

An extensive laboratory based investigation in to unprocessed low lime FA in foamed concrete, as a replacement for sand. The early age strengths were found to be similar for both sand and fly ash concrete; however the 28-day values varied significantly with density. The strength of fly ash concrete was more than 3 times higher than sand concrete. More significantly while the strength of sand mixes remained fairly constant beyond 28 days, those of fly ash foamed concrete at 56 and 180 days were up to 1.7 to 2.5 times higher than 28 days values respectively [17].

Aggregate cement ratio is only a secondary factor in the strength of concrete but it is found that, for a constant water cement ratio, a leaner mix leads to higher strength for higher aggregate cement ratio. A large amount of aggregate absorbs a greater quantity of water. It reduces the effective water cement ratio increasing the strength. The most likely explanation, however, lies in the fact that the total water content per cubic meter of concrete is lower in a leaner concrete. As a result, in a leaner mix, voids form a smaller fraction of total volume of concrete, and it is these voids that have an adverse effect on strength [24].

3.3. Effect on durability of concrete

The experimental results containing fly ash, the authors concluded that the pores in concrete reduce by addition of fly ash as replacement of sand increasing the durability of concrete [25]. The study on the use of fly ash as replacement of sand in polymer concrete. In the mix design 15% sand by weight was replaced with fly ash. They reported good surface finish due to addition of fly ash as replacement of sand which also reduce permeability and have an attractive dark colour. When subjected to 80 thermal cycles polymer concrete with fly ash exhibits slightly better thermal cycling resistance (about 7% improvement) than polymer concrete without fly ash [21].

Out of large number of papers studied, papers only found very relevant are included for putting forward present objectives. Literature discussed has shown partial replacement of sand with fly ash had shown higher strength from 3rd day as compared to control concrete. Long term strength was about 20% higher than the control concrete. Along with increase in strength, increase in workability and durability of concrete by partial replacement of sand with fly ash is very encouraging.

Analyzing the results it may be seen that due to ball bearing and pore filling effect, dispersion of cement particles and pozzolanic reactivity of fly ash as partial replacement of sand, workability and strength also increased. This additional strength and workability offered by partial replacement of sand with fly ash could offset loss of 28days strength of high volume fly ash concrete.

4. FINDINGS FROM LITERATURE REVIEW

- Literature shows that fly ash as a pozzolanic material is effective for improving the various properties of concrete.
- The advantages of fly ash are to increase the workability, while fibers increase strength by reducing crack opening and crack propagation.
- The disadvantage of fly ash is to reduce early age strength, while fibers reduce the workability of concrete.
- Advantages of fly ash as replacement of cement and addition of fibers in concrete on shrinkage and durability are very well reported in literature
- Effect of fly ash as partial replacement of cement and sand together with glass fibers is not available in literature
- Construction industry always require good workability and early age strength.
- The reduction of early age strength due to fly ash may be compensated by using glass fiber and reduction of workability due to fibers may be compensated by using fly ash in concrete.

5. DISCUSSION

Higher production and lesser consumption of fly ash will create big environmental issues for coming generations in Chhattisgarh, India. Also Government restriction on extraction of sand from river bed has recently resulted in many fold increase in its price. Production of one tone of cement discharges nearly equal amount of CO_2 into atmosphere and causes lot of harm to environment and society. For sustainability of sand and lime stone, there is a need of sustainable concrete by partially replacing sand and cement to save the environment.

The main disadvantage of replacement of cement with fly ash and fibers is to reduce 28 days strength and workability of concrete respectively. Researchers have shown that fibers in concrete increase strength and reduce cracks and crack propagation, while fly ash increases the workability of concrete due to its spherical shape. The issue of lower 28 days strength due to partial replacement of cement with fly ash may be addressed by use of fibers and partial replacement of sand with fly ash. Also reduction of workability due to addition of fiber may be compensated by addition of fly ash as replacement of cement and sand. A study on partial replacement of cement and sand by fly ash together with fiber for sustainable and durable concrete may be needed for higher consumption of fly ash and producing required days strength.

6. CONCLUSION

Use of fly ash and fibers is important for the sustainable construction and consumption of large volumes of fly ash. Literature discussed in the present paper has given an overview of effect of fly ash and different fibers on important properties of concrete. Present paper discussed the advantages of fly ash to increase the workability, durability, long term strength and reduce the heat of hydration of concrete. Fibers are also found more effective in resisting the development of cracks caused by shrinkage and loading. Today all the efforts of the concrete technologist should be in the direction of reduces the consumption of cement as it reduces CO_2 emission. Also environmental agencies are recommending lesser use of sand and higher consumption of fly ash. Fly ash together with fibers will make structures more durable making them sustainable and increasing service life. Fly ash concrete together with fibers fulfils all these requirements however the issue of lower early strength must be addressed by using fly ash, and workability is reduce using fiber but fly ash in the mixture may adjust the workability. Replacement of sand with fly together with fiber effect on durability of concrete not well studies and hence need to

be study for recommending partial replacement of sand with fly ash together with fiber for practice use. Also partial replacement of cement with fly ash and partial replacement of sand with fly ash together with fiber study not available and hence for high volume fly ash consumption in concrete such study is highly desired by the industry.

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REFERENCES

[1] Annual Report on Fly-ash utilization, Central Electricity Authority India 2015.

[2] R. K. Joshi (2013), “Fly ash scenario in India”Department of science and technology.

[3] Se Jin Choi ,Sang Soo Lee, and Paulo J. M. Monteiro, M.ASCE (2012), “Effect of Fly Ash Fineness on Temperature Rise, Setting, and Strength Development of Mortar”, journal of materials in civil engineering Vol. 24 PP 499-505.

[4] K. Holschemacher, T. Mulleller, Y. Ribakov (2010), “Effect of steel fibers on mechanical properties of concrete”, Materials & Design Vol-31, issue 5, PP: 2604-2615.

[5] Okan Karahan, Cengiz Duran Atis (2011), “The durability properties of polypropylene fiber reinforced fly ash concrete, Material and Design, VOL. 32, PP: 1044-1049.

[6] Cengiz Duran Atis, Okan Karahan (2009), “Properties of steel fiber reinforced fly ash concrete”, Construction and Building Materials Vol.23 PP: 392–399.

[7] Ilker Bekir Topcu, Mehmet Canbaz (2007), “Effect of different fibers on the mechanical properties of concrete containing fly ash”, Construction and Building Materials vol.21 PP: 1486–1491.

[8] Faiz A. Mirza, Parviz Soroushian (2002), “Effects of alkali-resistant glass fiber reinforcement on crack and temperature resistance of lightweight concrete”, Cement & Concrete Composites Vol. 24 PP: 223–227.

[9] Wei-Hsing Huang (2001), “Improving the properties of cement–fly ash grout using fiber and superplasticizer”, Cement and Concrete Research Vol. 31 PP: 1033–1041.

[10] Malhotra, V. M. and Mehta, P. K., (2002) “High-Performance, High- Volume Fly Ash Concrete: Materials, Mixture Proportioning, Properties, Construction Practice and Case Histories” Supplementary Cementing Materials for Sustainable Development Inc., Ottawa, Canada

[11] Mehta, P. K. and Monteriro, P. J. M. (2009) “Concrete – Microstructure, Properties and Materials”, Third Edition, Tata McGraw Hill.

[12] Bing Chen, Juanyu Liu (2003), “Effect of fibers on expansion of concrete with a large amount of high f-CaO fly ash”, Cement and Concrete Research Vol. 33 PP: 1549–1552

[13] Barluenga, F. Hernández-Olivares (2007), Cracking control of concretes modified with short AR-glass fibers at early age. Experimental results on standard concrete and SCC”, Cement and Concrete Research Vol. 37 PP:1624–1638

[14] Brahim Benmokrane, Peng Wang, Tan Minh Ton-That, Habib Rahman, and Jean-Francois Robert (2002), “Durability of Glass Fiber-Reinforced Polymer Reinforcing Bars in Concrete Environment”, journal of composites for construction vol. 6 PP: 143-153

[15] Gonzalo Barluenga (2010), “Fiber-matrix interaction at early ages of concrete with short fibers”, Cement and Concrete Research, Vol. 40, PP: 802-809

[16] A. Messan, P. Ienny, D. Nectous (2011), "Free and restrained early-age shrinkage of mortar: Influence of glass fiber, cellulose ether and EVA (ethylene-vinyl acetate), Cement and Concrete Composites, Vol-33, PP:402-410

[17] Jones, M. R. & McCarthy, A. (2005) "Utilizing Unprocessed Low Lime Coal Fly Ash in Foamed Concrete", Fuel, Vol 84, issue 11 pp-1398-1409.

[18] Rao, M V S, (2004)"Self Compacting High Performance Concrete" The Master Builder, Vol. 6, No.4 pp-84-90

[19] Pofale, A. D. and Deo, S. V. (2010), "Comparative Long study of Concrete Mix Design Procedure for Fine Aggregate Replacement with Fly Ash by Minimum Voids Method and Maximum Density Method", KSCE Journal of Civil Engineering, Vol. 14-Number 5, pp-759-764

[20] Rafat Siddique (2003) , "Effect of fine aggregate replacement with Class F fly ash on the mechanical properties of concrete", Cement and Concrete Research Vol. 33 PP: 539–547

[21] Rebeiz, K. S., Serhal, S. P. & Craft, A. P. (2004) "Properties of Polymer Concrete using Fly Ash", Journal of Materials Engineering, Vol-16, Issue 1, pp15-19.

[22] Namagg, C. and Atadero, R. A. (2009), "Optimisation of fly ash in Concrete: High Lime Fly Ash as a Replacement for Cement and Filler Material", Proceedings of World of Coal Ash Conference, 4-7 May, Lexington, USA, pp 1-6.

[23] P. Munusamy, R. Balaji and C. Sivakandhan, Analysis of Sand Mold Using Industrial Powders and Fly Ash. International Journal of Mechanical Engineering and Technology, 8(1), 2017, pp. 292–303.

[24] V. Keerthy and Y. Himath Kumar, Experimental Studies On Properties of Geopolymer Concrete with GGBS and Fly Ash. International Journal of Civil Engineering and Technology, 8(1), 2017, pp. 602–609.

[25] F. Anand Raju and Dr. M.L.S. Deva Kumar, Production and Mechanical Characterization of Al-7075-T6 and Fly Ash Composite by Stir Casting Hot Die Process. International Journal of Mechanical Engineering and Technology, 7(6), 2016, pp. 225–235.

[26] Papadakis, V.G. (1999), "Effect of Fly Ash on Portland Cement Systems Part-I: Low Calcium Fly Ash", Cement and Concrete Research, Vol. 29; issue 11, pp- 1727-1736.

[27] Neville, A. M. (2009), "Properties of concrete", Fourth Impression, Pearson Education.

[28] Hwang, K., Noguchi, T., and Tomosawa, F. (2004) "Prediction model of compressive strength development of fly ash concrete", Cement and Concrete research, vol-34, pp-2269-2276.